

EXHIBIT I



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Tao et al.

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(54) **LITHIUM-ION BATTERY HAVING DESIRABLE SAFETY PERFORMANCE**

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CPC H01M 10/0431; H01M 10/0587; H01M 50/531; H01M 50/533; H01M 50/538;
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(56) **References Cited**

U.S. PATENT DOCUMENTS

5,017,442 A	5/1991	Watanabe et al.
5,478,668 A	12/1995	Gozdz et al.

(Continued)

FOREIGN PATENT DOCUMENTS

CN 1350350 A	5/2002
CN 1221054 C	9/2005

(Continued)

OTHER PUBLICATIONS

Machine translation of WO2013038677A1 (Year: 2013).*
(Continued)

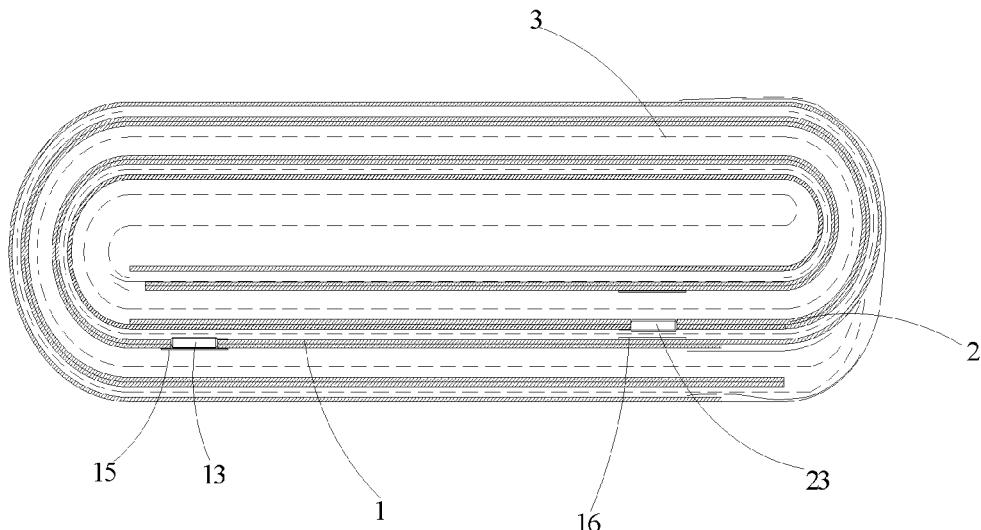
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(57) **ABSTRACT**

A lithium-ion battery having desirable safety performance includes a positive plate having a positive film, a negative plate having a negative film, a separator between the positive plate and the negative plate, and electrolyte. The positive film is provided with a first recess and a positive lead is soldered in the first recess. The negative film is provided with a second recess and a negative lead is soldered in the second recess. A first insulating glue layer is formed on an upper surface and below a lower surface of the positive lead. Surface of the positive film corresponding to the second recess is pasted with a second insulating glue layer.

22 Claims, 2 Drawing Sheets



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Related U.S. Application Data

No. 16/113,938, filed on Aug. 27, 2018, now abandoned, which is a continuation of application No. 14/596,873, filed on Jan. 14, 2015, now Pat. No. 10,541,441.

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H01M 50/536 (2021.01)
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See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

6,100,114 A	8/2000	Milkovich et al.	
6,300,002 B1	10/2001	Webb	
6,551,143 B2	4/2003	Tanaka et al.	
8,232,008 B2	7/2012	Morishima	
8,969,756 B2	3/2015	Dougherty	
9,935,339 B2	4/2018	Yoshida et al.	
10,062,897 B2	8/2018	Stern	
11,329,352 B2	5/2022	Guo	
2001/0036574 A1	11/2001	Fukuda et al.	
2004/0161662 A1	8/2004	Kim	
2006/0051662 A1*	3/2006	Kwak	H01M 10/0431
			429/130
2007/0122714 A1	5/2007	Suzuki et al.	
2007/0172736 A1*	7/2007	Fujikawa	H01M 50/474
			429/246
2009/0035638 A1	2/2009	Tsai et al.	
2011/0020694 A1	1/2011	Khakhalev et al.	
2011/0027636 A1*	2/2011	Lee	H01M 10/0431
			429/94
2011/0159344 A1	6/2011	Kobayashi	
2012/0052295 A1	3/2012	Iwata et al.	
2013/0052499 A1	2/2013	Hasegawa	
2013/0252053 A1	9/2013	Woo	
2013/0302674 A1	11/2013	Stern	
2014/0042121 A1	2/2014	Zhang et al.	
2014/0120417 A1*	5/2014	Matsushita	H01M 50/534
			429/211
2015/0207111 A1	7/2015	Tao	
2016/0013455 A1	1/2016	Shiu et al.	
2017/0092925 A1	3/2017	Shiu et al.	

FOREIGN PATENT DOCUMENTS

CN	1805183 A	7/2006
CN	201087907 Y	7/2008
CN	201336332 Y	10/2009
CN	101826609 A	9/2010
CN	101939873 A	1/2011
CN	102315477 A	1/2012
CN	202373667 U	8/2012
CN	202423456 U	9/2012
CN	202495523 U	10/2012
CN	202839841 U	3/2013
CN	103066239 A	4/2013
CN	103579666 A	2/2014
CN	203574050 U	4/2014
CN	203733894 U	7/2014
CN	104157914 A	11/2014
CN	204538109 U	8/2015

CN	204946995 U	1/2016	
CN	105514352 A	4/2016	
JP	H0513064 A	1/1993	
JP	1993013064 A	1/1995	
JP	1999317218 A	11/1999	
JP	2000-277155 A	10/2000	
JP	2000323135 A	11/2000	
JP	2003132875 A	5/2003	
JP	2007165224 A	* 6/2007	Y02P 70/50
JP	2007165224 A	6/2007	
JP	2010073653 A	4/2010	
WO	WO-2012072222 A1	6/2012	
WO	WO-2013038677 A1	* 3/2013	H01M 10/0587
WO	WO2013038677 A1	3/2013	

OTHER PUBLICATIONS

Machine translation of JP 2007165224 A (Year: 2007).*
Evaluation Report of Utility Model Patent, ZL2014200303194, dated Dec. 24, 2019, 5 pgs.
Tao, Office Action, U.S. Appl. No. 14/596,873, dated Apr. 4, 2017, 13 pgs.
Tao, Final Office Action, U.S. Appl. No. 14/596,873, dated Nov. 22, 2017, 13 pgs.
Tao, Office Action, U.S. Appl. No. 14/596,873, dated Apr. 19, 2018, 12 pgs.
Tao, Final Office Action, U.S. Appl. No. 14/596,873, dated Dec. 5, 2018, 13 pgs.
Tao, Office Action, U.S. Appl. No. 14/596,873, dated Mar. 22, 2019, 14 pgs.
Tao, Notice of Allowance, U.S. Appl. No. 14/596,873, dated Nov. 25, 2019, 7 pgs.
Tao, Office Action, U.S. Appl. No. 16/113,938, dated Aug. 16, 2019, 17 pgs.
Tao, Office Action, U.S. Appl. No. 16/113,938, dated Feb. 13, 2020, 22 pgs.
Tao, Office Action, U.S. Appl. No. 16/113,938, dated Nov. 2, 2020, 14 pgs.
Tao, Final Office Action, U.S. Appl. No. 16/113,938, dated May 20, 2021, 22 pgs.
Tao, Advisory Action, U.S. Appl. No. 16/113,938, dated Aug. 2, 2021, 3 pgs.
Machine English translation of CN202495523U (Year: 2012), 6 pgs.
Office Action, CN201580082766.1, dated May 27, 2020, 7 pgs.
Office Action, CN201580082766.1, dated Jan. 8, 2021, 7 pgs.
Office Action, CN201580082766.1, dated Jun. 2, 2021, 2 pgs.
International Search Report PCT/CN2015/088638, dated May 27, 2016, 5 pgs.
Guo, Office Action, U.S. Appl. No. 15/908,327, dated Oct. 24, 2019, 10 pgs.
Guo, Final Office Action, U.S. Appl. No. 15/908,327, dated Jan. 31, 2020, 9 pgs.
Guo, Office Action, U.S. Appl. No. 15/908,327, dated Oct. 19, 2020, 8 pgs.
Guo, Final Office Action, U.S. Appl. No. 15/908,327, dated Mar. 9, 2021, 8 pgs.
Guo, Office Action, U.S. Appl. No. 15/908,327, dated Jul. 23, 2021, 8 pgs.
Guo, Examiner-Initiated Interview Summary, U.S. Appl. No. 15/908,327, dated Dec. 6, 2021, 1 pg.
Guo, Notice of Allowance, U.S. Appl. No. 15/908,327, dated Jan. 12, 2022, 29 pg.
Guo, Office Action, U.S. Appl. No. 17/710,936, dated May 5, 2023, 14 pgs.
Machine translation of JP2007165224A, (Year: 2007), 8 pgs.
Machine translation of WO2013038677A1, (Year:2013), 15 pgs.
Professional translation of CN-101826609A, obtained May 1, 2023 (Year: 2010).
Professional translation of CN-104157914A, obtained May 1, 2023 (Year: 2014).
Tao, Office Action, U.S. Appl. No. 17/746,755, dated Mar. 31, 2023, 27 pgs.

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(56)

References Cited

OTHER PUBLICATIONS

Tao, Office Action, U.S. Appl. No. 17/746,755, dated Jul. 28, 2023,
18 pgs.

Tao, Office Action, U.S. Appl. No. 17/407,081, dated Aug. 5, 2022,
69 pgs.

Tao, Final Office Action, U.S. Appl. No. 17/407,081, dated Jan. 18,
2023, 19 pgs.

Zhuhai Cosmx Battery Co Ltd, Petitioner, v. *Ningde AmpereX Technology Limited*, Patent Owner, Petition for Inter Partes Review, Case No. IPR2023-00585, Mar. 31, 2023, 116 pgs.

* cited by examiner

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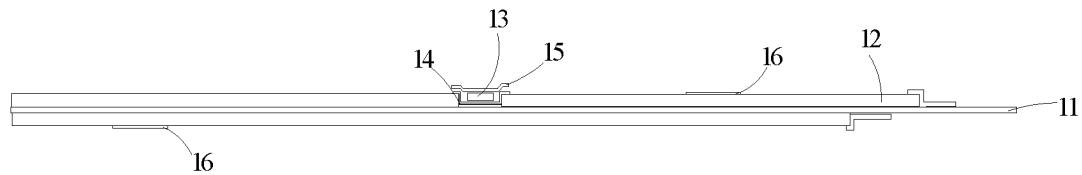


FIG. 1

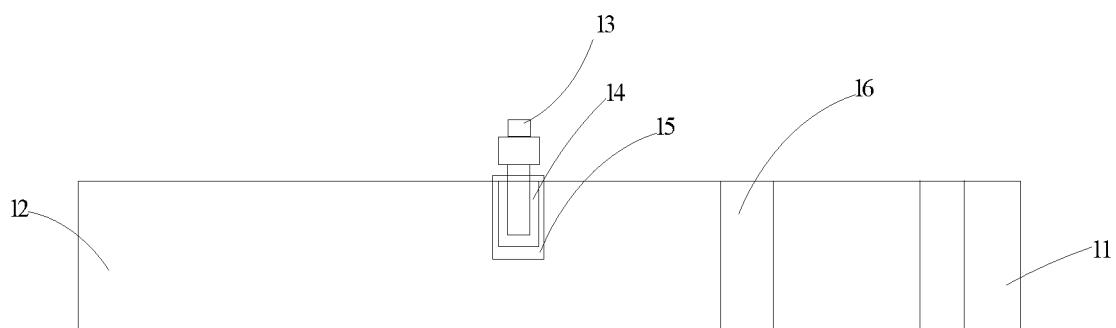


FIG. 2

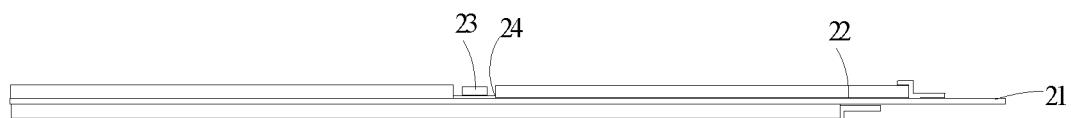


FIG. 3

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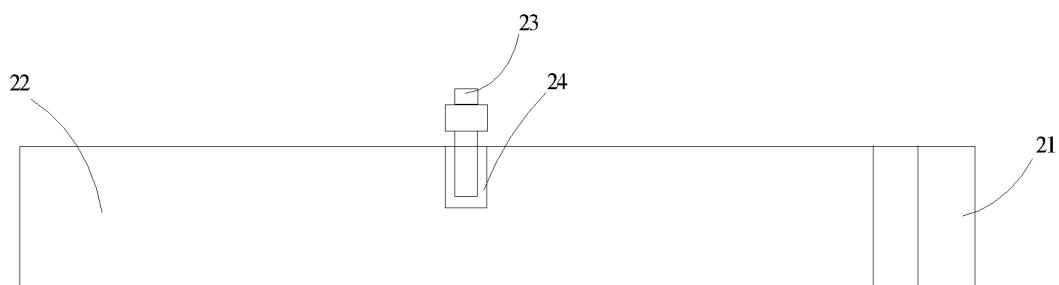


FIG. 4

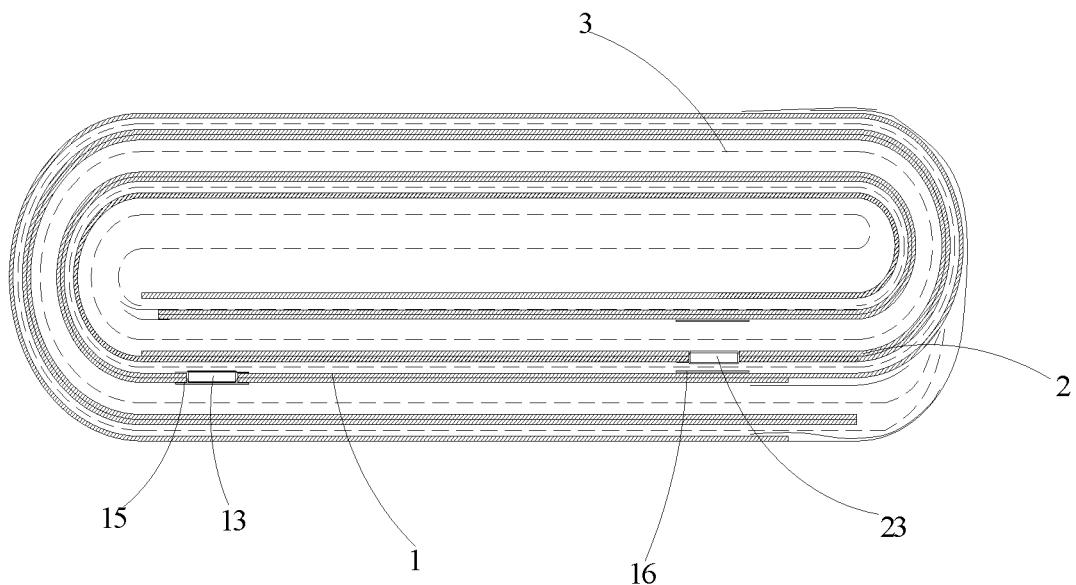


FIG. 5

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1**LITHIUM-ION BATTERY HAVING DESIRABLE SAFETY PERFORMANCE****CROSS-REFERENCE TO RELATED APPLICATION**

This application is a continuation of U.S. patent application Ser. No. 17/407,081, entitled "LITHIUM-ION BATTERY HAVING DESIRABLE SAFETY PERFORMANCE", filed on Aug. 19, 2021, which is a continuation application of U.S. patent application Ser. No. 16/113,938, entitled "LITHIUM-ION BATTERY HAVING DESIRABLE SAFETY PERFORMANCE", filed Aug. 27, 2018, which is a continuation of U.S. patent application Ser. No. 14/596,873, entitled "LITHIUM-ION BATTERY HAVING DESIRABLE SAFETY PERFORMANCE", filed Jan. 14, 2015, which claims priority to Chinese Patent Application No. 201420030319.4, entitled "LITHIUM-ION BATTERY HAVING DESIRABLE SAFETY PERFORMANCE", filed Jan. 17, 2014, all of which are hereby incorporated by reference in their entirety.

TECHNICAL FIELD

The present disclosure generally relates to lithium-ion batteries and, more particularly, relates to a lithium-ion battery having desirable safety performance.

BACKGROUND

At present, lithium-ion batteries are required to be thinner and thinner as well as have higher and higher energy density, which demands a lithium-ion battery has as much energy as possible in a volume as small as possible.

In conventional design of a lithium-ion battery, a lead is a component soldered on a current collector to conduct current. Arrangement of the lead will increase the thickness of the lithium-ion battery no matter the lithium-ion battery adopts a Jelly-roll structure or a laminated structure. In other words, the area where the lead is soldered to the current collector has a largest thickness in the lithium-ion battery. The increased thickness due to the lead is about 1-5% of the thickness of an assembled lithium-ion battery. Therefore, increase of thickness of a lithium-ion battery due to the lead has become one of the key actors which limit the energy density of the lithium-ion battery.

Chinese patent publication numbers CN 202495523U and CN 201087907Y each discloses a lithium-ion battery which defines a recess on a positive plate and/or the negative plate to receive a lead therein. The arrangement of the recess on the positive plate and/or the negative plate can reduce the thickness of the lithium-ion battery. However, when the recess is defined at one end of the positive plate or the negative plate along a length direction thereof, thickness variation around the recess is much larger than the thickness variation of the film afar from the recess. Particularly, the arrangement of the recess may generate a number of corners. The film around the corners is readily peeled off, especially when the negative active material adopts an expansive substance, such as silicon. The structure as previously described may lead to a high internal resistance of the lithium-ion battery and affect the capacity of the lithium-ion battery. In addition, there is no insulating layer provided on the positive area corresponding to the positive recess or the negative recess, internal short circuit and lithium precipita-

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tion may potentially occur to the lithium-ion battery, which will inevitably affect the safety performance of the lithium-ion battery.

In view of the foregoing, what is needed, therefore, is to provide a lithium-ion battery having desirable safety performance.

SUMMARY

10 One object of the present disclosure is to provide a battery which has high energy density and desirable safety performance.

According to an embodiment of the present disclosure, a battery is provided and the battery includes: a first plate, comprising a first film and a first lead; a first insulating glue layer, disposed on a surface of the first lead; a second plate, comprising a second lead; in which a second insulating glue layer is disposed on a surface of the first film corresponding to the second lead.

20 According to an embodiment of the present disclosure, the first plate includes a first current collector, the first film and the first lead, the first film being disposed on the first current collector, the first lead being electrically connected with the first current collector, the first film includes: a first recess configured to receive the first lead; a second plate, comprising a second current collector, a second film and a second lead, the second film being disposed on the second current collector, the second lead being electrically connected with the second current collector, the second film being provided with a second recess configured to receive the second lead.

30 Specifically, the first plate is a positive plate, the first current collector is a positive current collector, the first film is a positive film, the first lead is a positive lead; the second plate is a negative plate, the second current collector is a negative current collector, the second film is a negative film, the second lead is a negative lead.

According to one embodiment of the present disclosure, a lithium-ion battery having desirable safety performance is provided. The lithium-ion battery includes:

40 a positive plate, including a positive current collector, a positive film formed on the positive current collector and a positive lead coupled to the positive current collector, the positive film being provided with a first recess and the positive lead being soldered in the first recess;

45 a negative plate, including a negative current collector, a negative film formed on the negative current collector and a negative lead coupled to the negative current collector, and the negative film being provided with a second recess and the negative lead being soldered in the second recess;

50 a separator disposed between the positive plate and the negative plate; and electrolyte,

wherein upper and lower surfaces of the positive lead each is provided with a first insulating glue layer, a surface of the positive film corresponding to the second recess is pasted with a second insulating glue layer, and the first insulating glue layer formed on the lower surface of the positive lead entirely covers the blank positive current collector in the first recess.

60 According to an embodiment of the present disclosure, the positive lead is entirely seated in the first recess and the negative lead is entirely seated in the second recess. Due to the arrangement of the first recess on the positive plate and the second recess on the negative plate, the positive lead and the negative lead can be received in the first recess and the second recess respectively. Along the thickness direction, the thickness of the positive lead (negative lead) is less than

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the thickness of the positive plate (negative plate). Therefore, the lead will not induce thickness increase of the positive lead or the negative lead. There will be more space for the active material, and energy density of the lithium-ion battery is improved remarkably.

According to an embodiment of the present disclosure, the first recess or the second recess is defined via mechanical solvent cleaning or laser cleaning.

According to an embodiment of the present disclosure, the second insulating glue layer has a width larger than a width of the second recess, and the second insulating glue layer has a length larger than a length of the second recess.

According to an embodiment of the present disclosure, the first insulating glue layer or the second insulating glue layer is one of a green insulating glue layer, a black insulating glue layer, a white insulating glue layer or a yellow insulating glue layer.

According to an embodiment of the present disclosure, a distance between a center of the first recess and one end of the positive film is $\frac{1}{4}\sim\frac{3}{4}$ of a length of the positive film, and a distance between a center of the second recess and one end of the negative film is $\frac{1}{4}\sim\frac{3}{4}$ of a length of the negative film.

According to an embodiment of the present disclosure, the first recess and the second recess are defined in a middle portion of the positive plate and the negative plate respectively. Even though the positive plate and/or the negative plate expand, unstable bonding, large thickness variation or even abscission of the positive film or the negative film around the recess is avoided. At the same time, the internal resistance of the lithium-ion battery is reduced, and capacity and energy density of the lithium-ion battery are improved remarkably in the premise of unchanged battery cell size.

According to an embodiment of the present disclosure, a distance between a center of the first recess and one end of the positive film is half of a length of the positive film, and a distance between a center of the second recess and one end of the negative film is half of a length of the negative film.

According to an embodiment of the present disclosure, the first recess has a length $1\sim100$ mm less than a length of the positive lead, the first recess has a width $1\sim10$ mm larger than a width of the positive lead, the second recess has a length $1\sim100$ mm less than a length of the negative lead, and the second recess has a width $1\sim10$ mm larger than a width of the negative lead.

According to an embodiment of the present disclosure, the first recess has a length $1\sim100$ mm less than a width of the positive film, and the second recess has a length $1\sim100$ mm less than a width of the negative film.

According to an embodiment of the present disclosure, the first recess has a depth no larger than a thickness of the positive film, and the second recess has a depth no larger than a thickness of the negative film.

According to an embodiment of the present disclosure, the first recess has a depth $0.005\sim0.1$ mm larger than a thickness of the positive lead, and the second recess has a depth $0.005\sim0.1$ mm larger than a depth of the negative lead.

Compared with the prior art, due to the arrangement of the first insulating glue layer formed on the upper and lower surfaces of the positive lead and the second insulating glue layer pasted on the surface of the positive film corresponding to the second recess, occurrence of internal short circuit and lithium precipitation in the lithium-ion battery is remarkably reduced, and safety performance of the lithium-ion battery is improved remarkably in the premise of desirable energy density.

Other advantages and novel features will be drawn from the following detailed description of preferred embodiments

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with the attached drawings. The accompanying drawings, which are incorporated in and constitute a part of this specification, illustrate embodiments of the present disclosure and, together with a general description of the disclosure given above, and the detailed description of the embodiments given below, serve to explain the principles of the disclosure:

BRIEF DESCRIPTION OF THE DRAWINGS

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FIG. 1 depicts an exemplary front view of a positive plate of a lithium-ion battery according to one embodiment of the present disclosure;

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FIG. 2 depicts an exemplary view of a positive plate of a lithium-ion battery according to one embodiment of the present disclosure;

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FIG. 3 depicts an exemplary front view of a negative plate of a lithium-ion battery according to one embodiment of the present disclosure;

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FIG. 4 depicts an exemplary top view of a negative plate of a lithium-ion battery according to one embodiment of the present disclosure; and

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FIG. 5 depicts an exemplary cross-sectional view of a lithium-ion battery according to one embodiment of the present disclosure.

DETAILED DESCRIPTION

Example embodiments of the present disclosure will now be described more fully hereinafter with reference to the accompanying drawings, in which some, but not all embodiments of the disclosure are shown. Indeed, the disclosure may be embodied in many different forms and should not be construed as limited to the embodiments set forth herein; rather, these embodiments are provided so that this disclosure will satisfy applicable legal requirements. Like reference numerals refer to like elements throughout.

According to an embodiment of the present disclosure, a battery is provided and the battery includes: a first plate, comprising a first film and a first lead; a first insulating glue layer, disposed on a surface of the first lead; a second plate, comprising a second lead; in which a second insulating glue layer is disposed on a surface of the first film corresponding to the second lead.

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According to an embodiment of the present disclosure, the first plate includes a first current collector, the first film and the first lead, the first film being disposed on the first current collector, the first lead being electrically connected with the first current collector, the first film includes: a first recess configured to receive the first lead; a second plate, comprising a second current collector, a second film and a second lead, the second film being disposed on the second current collector, the second lead being electrically connected with the second current collector, the second film being provided with a second recess configured to receive the second lead.

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Specifically, the first plate is a positive plate, the first current collector is a positive current collector, the first film is a positive film, the first lead is a positive lead; the second plate is a negative plate, the second current collector is a negative current collector, the second film is a negative film, the second lead is a negative lead.

Example 1

Referring to FIG. 1 to FIG. 5, a lithium-ion battery according to one embodiment of the present disclosure

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includes a positive plate 1, a negative plate 2, a separator 3 disposed between the positive plate 1 and the negative plate 2, and electrolyte (not shown). The positive plate 1 includes a positive current collector 11, a positive film 12 provided on the positive current collector 11, and a positive lead 13. The negative plate 2 includes a negative current collector 21, a negative film 22 provided on the negative current collector 21, and a negative lead 23. The positive film 12 defines a first recess 14. The positive lead 13 is soldered and seated in the first recess 14. The negative film 22 defines a second recess 24. The negative lead 23 is soldered and seated in the second recess 24. An upper surface and a lower surface of the positive lead 13 each is formed with a first insulating glue layer 15. A surface of the positive film 12 corresponding to the second recess 24 is pasted with a second insulating glue layer 16.

The second insulating glue layer 16 has a width larger than a width of the second recess 24. The second insulating glue layer 16 has a length larger than a length of the second recess 24.

The first insulating glue layer 15 and the second insulating glue layer 16 are green insulating glue layers.

The distance between the center of the first recess 14 and one end of the positive film 12, i.e. one end of the positive film 12 perpendicular to a length direction of the positive current collector 11 and formed no blank positive current collector 11, is half of a length of the positive film 12. The distance between the center of the second recess 24 and one end of the negative film 22, i.e. one end of the negative film 12 perpendicular to a length direction of the negative current collector 21 and formed no blank negative current collector 21, is half of a length of the negative film 22.

The first recess 14 has a length 25 mm less than a length of the positive lead 13. The first recess 14 has a width 4 mm larger than a width of the positive lead 13. The second recess 24 has a length 25 mm less than a length of the negative lead 23. The second recess has a width 4 mm larger than a width of the negative lead 23.

The first recess 14 has a length 55 mm less than a width of the positive film 13. The second recess 24 has a length 57 mm less than a width of the negative film 22.

The first recess 14 has a depth less than a thickness of the positive film 12. The second recess 24 has a depth less than a thickness of the negative film 22.

The first recess 14 has a depth 0.02 mm larger than a thickness of the positive lead 13. The second recess 24 has a depth 0.02 mm larger than a thickness of the negative lead 23.

A method for manufacturing a lithium-ion battery according to one embodiment of the present disclosure will be described in detail in view of a 303482 square lithium-ion battery (a lithium-ion battery having a thickness of 3.0 mm, a width of 34 mm and a length of 82 mm). The method for manufacturing a lithium-ion battery includes the steps of:

Preparation of the Positive Plate:

- 1) adding 95 wt % positive active material LiCoO₂, 2 wt % binder PVDF and 3 wt % conductive agent graphite into solvent NMP, obtaining a positive slurry having a viscosity of 3000-6000 pa·s after fully stirring;
- 2) coating the positive slurry on an aluminum foil having a thickness of 12 µm, and obtaining a positive plate 1 having a compacted density of 4.1 g/cm³ and a length of 277 mm, a width of 75 mm, a thickness of 0.114 mm after drying and cold pressing;
- 3) removing the positive film 12 at a center of the positive plate 1 (at a middle portion along a length direction of the

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positive plate 1) via laser cleaning to define a first recess 14 having a thickness of 0.1 mm, a width of 10 mm and a length of 20 mm;

- 4) coupling a positive lead 13 having a thickness of 0.08 mm, a width of 6 mm and a length of 45 mm in the first recess 14 via laser welding, the positive lead 13 extending out of the positive plate 1 of about 15 mm;
- 5) providing green insulating glue layers on upper and lower surfaces of the positive lead 13, and pasting green insulating glue layer on the positive film 12 corresponding to the second recess 24 in winding, ensuring the green insulating glue layer on the lower surface of the positive lead 13 entirely covering the blank positive current collector 11 in the first recess 14.

Preparation of the Negative Plate:

- 1) adding 95 wt % negative active material graphite, 2 wt % bonding agent SBR, 1 wt % thickener CMC and 2 wt % conductive agent graphite in solvent deionized water, and obtaining negative slurry having a viscosity of 1000-3000 pa·s after fully stirring;
- 2) coating the negative slurry on a copper foil having a thickness of 6 µm, after drying and cold pressing, obtaining a negative plate having a compaction density of about 1.6 g/cm³ and a length of 285 mm, a width of 77 mm, a thickness of 0.135 mm;
- 3) removing the negative active material at a center of the negative plate 2 (at a middle portion along a length direction of the negative plate 2) via mechanical cleaning to define a second recess 24, the second recess 24 having a thickness of 0.10 mm, a width of 10 mm and a length of 20 mm;
- 4) providing a negative lead 23 having a thickness of 0.08 mm, a width of 6 mm and a length of 45 mm, soldering the negative lead 23 in the second recess 24, with the negative lead 23 extending out of the negative plate 2 of 15 mm.

Preparation of the electrolyte: fully mixing a mixture of methyl ethyl carbonate (EMC), diethyl carbonate (DEC), ethylene carbonate (EC) and propylene carbonate (PC) having a weight ratio of 1:1:0.5:0.5; adding LiPF₆ as solute and obtaining a base electrolyte containing 1M LiPF₆; adding 0.5 wt % of two fluorine lithium oxalate borate and 1 wt % of adiponitrile in the base electrolyte, and obtaining electrolyte for use in a lithium-ion battery after fully dissolving.

Preparation of the lithium-ion battery: coiling the positive plate 1 and the negative plate 2 with a separator polyethylene film 3 having a thickness of 0.013 mm interposed between the positive plate 1 and the negative plate 2 and obtaining a bared battery cell, with main portion of the bared battery cell having an average thickness of about 2.78 mm; obtaining a final lithium-ion battery after drying the bared battery cell, pouring the electrolyte and packaging.

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Example 2

Example 2 is Almost the Same as Example 1,
Except that

- 60 The distance between a center of the first recess 14 and one end of the positive film 12 (one end of the positive film 12 perpendicular to a length direction of the positive current collector 11 and formed no blank positive current collector 11) is about ¼ of the length of the positive film 12.
- 65 The distance between a center of the second recess 24 and one end of the negative film 22 (one end of the negative film 22 perpendicular to a length direction of the negative current

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collector **21** and formed no blank negative current collector **21** is about $\frac{1}{4}$ of the length of the negative film **12**.

The first recess **14** has a length 75 mm less than a length of the positive lead **13**. The first recess **14** has a width 2 mm larger than a width of the positive lead **13**. The second recess **24** has a length 75 mm less than a length of the negative lead **23**. The second recess **24** has a width 2 mm larger than a width of the negative lead **23**.

The first recess **14** has a length 30 mm less than a width of the positive film **12**. The second recess **24** has a length 33 mm less than a width of the negative film **22**.

The first recess **14** has a depth 0.08 mm larger than a thickness of the positive lead **13**. The second recess **24** has a depth 0.08 mm larger than a thickness of the negative lead **23**.

The negative active material is silicon.

The first insulating glue layer **15** and the second insulating glue layer **16** are black insulating glue layers.

Other features of Example 2 are the same as have described in Example 1 and will not be detailed further.

Example 3

Example 3 is Almost the Same as Example 1,
Except that

The distance between a center of the first recess **14** and one end of the positive film **12** (one end of the positive film **12** perpendicular to a length direction of the positive current collector **11** and formed no blank positive current collector **11**) is about $\frac{3}{4}$ of the length of the positive film **12**.

The distance between a center of the second recess **24** and one end of the negative film **22** (one end of the negative film **22** perpendicular to a length direction of the negative current collector **21** and formed no blank negative current collector **21**) is about $\frac{3}{4}$ of the length of the negative film **12**.

The first recess **14** has a length 50 mm less than a length of the positive lead **13**. The first recess **14** has a width 8 mm larger than a width of the positive lead **13**. The second recess **24** has a length 50 mm less than a length of the negative lead **23**. The second recess **24** has a width 8 mm larger than a width of the negative lead **23**.

The first recess **14** has a length 70 mm less than a width of the positive film **12**. The second recess **24** has a length 73 mm less than a width of the negative film **22**.

The first recess **14** has a depth 0.05 mm larger than a thickness of the positive lead **13**. The second recess **24** has a depth 0.05 mm larger than a thickness of the negative lead **23**.

The negative active material is silicon.

The first insulating glue layer **15** and the second insulating glue layer **16** are white insulating glue layers.

Other features of Example 3 are the same as have described in Example 1 and will not be detailed further.

Example 4

Example 4 is Almost the Same as Example 2,
Except that

The distance between a center of the first recess **14** and one end of the positive film **12** (one end of the positive film **12** perpendicular to a length direction of the positive current collector **11** and formed no blank positive current collector **11**) is about $\frac{1}{6}$ of the length of the positive film **12**.

The distance between a center of the second recess **24** and one end of the negative film **22** (one end of the negative film

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22 perpendicular to a length direction of the negative current collector **21** and formed no blank negative current collector **21**) is about $\frac{1}{6}$ of the length of the negative film **12**.

The first insulating glue layer **15** and the second insulating glue layer **16** are yellow insulating glue layer.

Other features of Example 4 are the same as have described in Example 2 and will not be detailed further.

Example 5

Example 5 is Almost the Same as Example 3,
Except that

15 The distance between a center of the first recess **14** and one end of the positive film **12** (one end of the positive film **12** perpendicular to a length direction of the positive current collector **11** and formed no blank positive current collector **11**) is about $\frac{4}{5}$ of the length of the positive film **12**.

20 The distance between a center of the second recess **24** and one end of the negative film **22** (one end of the negative film **22** perpendicular to a length direction of the negative current collector **21** and formed no blank negative current collector **21**) is about $\frac{4}{5}$ of the length of the negative film **12**.

25 Other features of Example 5 are the same as have described in Example 3 and will not be detailed further.

Comparative Example 1

30 The Comparative Example 1 is almost the same as Example 1, except that, upper and lower surfaces of the positive lead **13** have no first insulating glue layer **15** formed thereon. The surface of the positive film **12** corresponding to the second recess **24** has no second insulating glue layer **16** pasted thereon.

35 Other features of Comparative Example 1 are the same as have described in Example 1 and will not be detailed further.

Comparative Example 2

40 The Comparative Example 2 is almost the same as Example 1, except that, the positive lead **13** is soldered to the blank positive current collector **11**, the positive film **12** does not have a first recess **14**, the negative lead **23** is soldered to the blank negative current collector **21**, the negative film **22** does not have a second recess **24**. Other features of Comparative Example 2 are the same as have described in Example 1 and will not be detailed further.

45 **50** 10 lithium-ion batteries are randomly selected from lithium-ion batteries according to Example 1, Example 2, Example 3 and Comparative Example 1 respectively. Each lithium-ion battery is carried out a cycle performance test of 300 cycles. Number of the lithium-ion batteries occurring short circuit is calculated and the testing result is shown in Table 1.

55 **60** 10 lithium-ion batteries are randomly selected from lithium-ion batteries according to Example 1, Example 2, Example 3 and Comparative Example 1 respectively. Each lithium-ion battery is carried out a cycle performance test of 100 cycles. Each lithium-ion battery is disassembled to observe lithium precipitation on the negative plate **2**. Number of lithium-ion batteries whose negative plate **2** occurs lithium precipitation is calculated and the testing result is shown in Table 2.

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TABLE 1

Short circuit and lithium precipitation on the negative plate occurs to lithium-ion batteries according to Examples 1 to 3 and Comparative Example 1 after cycle test		
Group	Number of batteries occurring short circuit after 300 cycles	Number of batteries occurring lithium precipitation on the negative plate after 100 cycles
Example 1	0	0
Example 2	0	1
Example 3	1	0
Comparative Example 1	5	7

As clearly shown in Table 1, due to the first insulating glue layer 15 formed on the upper and lower surfaces of the positive lead 13 and the second insulating glue layer 16 pasted on the surface of the positive film 12 corresponding to the second recess 24, the safety performance of the lithium-ion battery can be improved remarkably.

Capacity test, internal resistance test and volumetric energy density test are carried out to the lithium-ion batteries according to Example 1 and Comparative Example 2. The test result is shown in Table 2. The capacity test and internal resistance test are carried out on hang machine at 25°C., the discharge capacity is 0.2C, the internal resistance is impedance under 1000 Hz, and the volumetric energy density=minimum capacity×platform voltage/maximum volume.

TABLE 2

Capacity, internal resistance and volumetric energy density of lithium-ion batteries according to Example 1 and Comparative Example 2				
Group	DC resistance (mΩ)	Average capacity (mAh)	Average thickness (mm)	Average volumetric energy density(Wh/L)
Example 1	55	1180	2.78	563
Comparative Example 1	62	1170	2.84	546
Example 2				

As clearly shown in Table 2, the structure of the positive plate and negative plate according to the present disclosure can overcome uneven thickness of the battery cell, so as to efficiently utilize the space of the lithium-ion battery, improve the capacity and the volumetric energy density of the lithium-ion battery, and reduce the internal resistance of the lithium-ion battery.

Charging and discharging cycle tests are carried out to lithium-ion batteries in accordance with Examples 2 to 5, in which for the sake of illustration, the negative active material in Example 1 is substituted by silicon and referenced as Example 6. The lithium-ion batteries are disassembled after 50 cycles. Abscission of active material at the edge of the second recess 24 is shown in Table 3.

TABLE 3

Abscission of active material at the edge of the second recess after charging and discharging cycle test of lithium-ion batteries according to Examples 2 to 6					
	Example 4	Example 2	Example 6	Example 3	Example 5
Abscission of active material at the second recess	Obvious abscission of active material	No obvious abscission of active material	No abscission of active material	No abscission of active material	Obvious abscission of active material

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TABLE 3-continued

Abscission of active material at the edge of the second recess after charging and discharging cycle test of lithium-ion batteries according to Examples 2 to 6				
recess after 50 cycles	Example 4	Example 2	Example 6	Example 3
material	material	material	material	material

As clearly shown in Table 3, if the negative active material for use in the negative plate 2 is apt to serious volume expansion, such as silicon, the first recess 14 in the center of the positive plate 1 and the second recess 24 in the center of the negative plate 2 can effectively reduce abscission of active material at the edge of the second recess 24. The negative plate 2 adopting silicon as active material undertakes serious volume expansion, which may cause the negative plate 2 defining the second recess at one end thereof, cannot bear the uneven force at the second recess. However, the second recess 24 as described in Examples 2, 3 and 6 each is located in the center of the negative plate 2. Two ends of the negative plate 2 bear almost the same forces and, therefore, abscission of active material at the edge of the second recess 24 can be improved remarkably.

Many modifications and other embodiments of the disclosure set forth herein will come to mind to one skilled in the art to which these disclosure pertain having the benefit of the teachings presented in the foregoing descriptions and the associated drawings. Therefore, it is to be understood that the disclosure are not to be limited to the specific embodiments disclosed and that modifications and other embodiments are intended to be included within the scope of the appended claims. Moreover, although the foregoing descriptions and the associated drawings describe example embodiments, it should be appreciated that alternative embodiments without departing from the scope of the appended claims. Although specific terms are employed herein, they are used in a generic and descriptive sense only and not for purposes of limitation.

What is claimed is:

1. A lithium-ion battery, comprising:
a positive electrode comprising a positive current collector and a positive electrode active material layer containing LiCoO₂, wherein the positive electrode active material layer is formed on the positive current collector, the positive electrode active material layer being provided with a first recess accommodating a positive lead being coupled with the positive current collector;
a negative electrode comprising a negative current collector and a negative electrode active material layer containing graphite or silicon, wherein the negative electrode active material layer is formed on the negative current collector, the negative electrode active material layer being provided with a second recess accommodating a negative lead being coupled with the negative current collector;
a separator disposed between the positive electrode and the negative electrode; and
an electrolyte,
wherein, a top surface of the positive lead is provided with a first insulating glue layer, a surface of the positive electrode active material layer opposite to the second recess across the separator in a thickness direction of the positive plate and the negative plate is pasted with a second insulating glue layer, the second insulating glue layer has a width larger than a width of the second

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recess, and the second insulating glue layer has a length larger than a length of the second recess.

2. The lithium-ion battery of claim 1, wherein a distance between a center of the first recess and one end of the positive electrode active material layer is $\frac{1}{4}$ - $\frac{3}{4}$ of a length of the positive electrode active material layer; and a distance between a center of the second recess and one end of the negative electrode active material layer is $\frac{1}{4}$ - $\frac{3}{4}$ of a length of the negative electrode active material layer. 5

3. The lithium-ion battery of claim 2, wherein, the distance between the center of the first recess and the one end of the positive electrode active material layer is half of the length of the positive electrode active material layer; and the distance between the center of the second recess and the one end of the negative electrode active material layer is half of the length of the negative electrode active material layer. 15

4. The lithium-ion battery of claim 3, wherein the first recess has a length of 1-100 mm less than a length of the positive lead, the first recess has a width of 1-10 mm larger than a width of the positive lead, the second recess has a length of 1-100 mm less than a length of the negative lead, and the second recess has a width of 1-10 mm larger than a width of the negative lead. 20

5. The lithium-ion battery of claim 1, wherein the first recess has a length of 1-100 mm less than a width of the positive electrode active material layer, and the second recess has a length of 1-100 mm less than a width of the negative electrode active material layer. 25

6. The lithium-ion battery of claim 1, wherein the first recess has a depth of 0.005-0.1 mm larger than a thickness of the positive lead, and the second recess has a depth of 0.005-0.1 mm larger than a thickness of the negative lead. 30

7. The lithium-ion battery of claim 1, wherein a length of a portion of the positive lead in the first recess is less than a width of a remaining portion of the positive electrode active material layer from an edge of the first insulating glue layer covering the positive electrode active material layer to an edge of the positive electrode active material layer opposite to the first recess. 35

8. The lithium-ion battery of claim 1, wherein a width of a portion of the positive lead in the first recess is greater than a width of a remaining portion of the first recess not occupied by the positive lead located on one side of the positive lead. 40

9. A lithium-ion battery, comprising:

a positive electrode, comprising a positive current collector and a positive electrode active material layer being formed on the positive current collector, the positive electrode active material layer being provided with a first recess accommodating a positive lead being coupled with the positive current collector; 50

a negative electrode, comprising a negative current collector and a negative electrode active material layer being formed on the negative current collector, the negative electrode active material layer being provided with a second recess accommodating a negative lead being coupled with the negative current collector; a separator disposed between the positive electrode and the negative electrode; and an electrolyte. 55

wherein, a first location of a top surface of the positive lead is provided with a first insulating glue layer; a second location of a surface of the positive electrode active material layer opposite to the second recess across the separator in a thickness direction of the positive plate and the negative plate is pasted with a second insulating glue layer; a third location of a 60

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surface of the positive current collector opposite to the surface of the positive current collector where the positive lead is covered with another first insulating glue layer; the second insulating glue layer has a width larger than a width of the second recess, and the second insulating glue layer has a length larger than a length of the second recess. 65

10. The lithium-ion battery of claim 9, wherein a distance between a center of the first recess and one end of the positive electrode active material layer is $\frac{1}{4}$ - $\frac{3}{4}$ of a length of the positive electrode active material layer, and a distance between a center of the second recess and one end of the negative electrode active material layer is $\frac{1}{4}$ - $\frac{3}{4}$ of a length of the negative electrode active material layer. 15

11. The lithium-ion battery of claim 9, wherein a distance between a center of the first recess and one end of the positive electrode active material layer is half of a length of the positive electrode active material layer, and a distance between a center of the second recess and one end of the negative electrode active material layer is half of a length of the negative electrode active material layer. 20

12. The lithium-ion battery of claim 9, wherein the first recess has a length of 1-100 mm less than a length of the positive lead, the first recess has a width of 1-10 mm larger than a width of the positive lead, the second recess has a length of 1-100 mm less than a length of the negative lead, and the second recess has a width of 1-10 mm larger than a width of the negative lead. 25

13. The lithium-ion battery of claim 9, wherein the first recess has a length of 1-100 mm less than a width of the positive electrode active material layer, and the second recess has a length of 1-100 mm less than a width of the negative electrode active material layer. 30

14. The lithium-ion battery of claim 9, wherein the first recess has a depth of 0.005-0.1 mm larger than a thickness of the positive lead, and the second recess has a depth of 0.005-0.1 mm larger than a thickness of the negative lead. 35

15. The lithium-ion battery of claim 9, wherein a length of a portion of the positive lead in the first recess is less than a width of a remaining portion of the positive electrode active material layer from an edge of the first insulating glue layer covering the positive electrode active material layer to an edge of the positive electrode active material layer opposite to the first recess. 40

16. The lithium-ion battery of claim 9, wherein a width of a portion of the positive lead in the first recess is greater than a width of a remaining portion of the first recess not occupied by the positive lead located on one side of the positive lead. 45

17. A lithium-ion battery, comprising:

a positive electrode, comprising a positive current collector and a positive electrode active material layer being formed on the positive current collector, the positive electrode active material layer being provided with a first recess accommodating a positive lead being coupled with the positive current collector; 50

a negative electrode, comprising a negative current collector and a negative electrode active material layer being formed on the negative current collector, the negative electrode active material layer being provided with a second recess accommodating a negative lead being coupled with the negative current collector; a separator disposed between the positive electrode and the negative electrode; and an electrolyte. 55

wherein, a first location of a top surface of the positive lead is provided with a first insulating glue layer; a 60

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second location of a surface of the positive electrode active material layer opposite to the second recess across the separator in a thickness direction of the positive plate and the negative plate is pasted with a second insulating glue layer; the second insulating glue layer has a width larger than a width of the second recess, and the second insulating glue layer has a length larger than a length of the second recess.

18. The lithium-ion battery of claim **17**, wherein a length of a portion of the first lead in the first recess is less than a width of a remaining portion of a first film from an edge of the first insulating glue layer covering the first film to an edge of the first film opposite to the first recess.

19. The lithium-ion battery of claim **17**, wherein a width of a portion of the first lead in the first recess is greater than a width of a remaining portion of the first recess not occupied by the first lead located on one side of the first lead.

20. The lithium-ion battery of claim **1**, wherein two insulating layers are disposed on two opposite surfaces of

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the positive plate, and a winding end of the negative plate is located between the two insulating layers; and the two insulating layers extend over the winding end of the negative plate along the winding direction.

5 **21.** The lithium-ion battery of claim **9**, wherein two insulating layers are disposed on two opposite surfaces of the positive plate, and a winding end of the negative plate is located between the two insulating layers; and the two insulating layers extend over the winding end of the negative plate along the winding direction.

10 **22.** The lithium-ion battery of claim **17**, wherein two insulating layers are disposed on two opposite surfaces of the positive plate, and a winding end of the negative plate is located between the two insulating layers; and the two insulating layers extend over the winding end of the negative plate along the winding direction.

* * * * *